Managing Financial Implications for Sustainable Highway Project Delivery

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Abstract: Highway construction works have significant bearings on all aspects of sustainability. As they typically involve huge capital funds, stakeholders tend to place all interests on the financial justifications of the project, especially when embedding sustainability principles and practices may demand significant initial investment. Increasing public awareness and government policies demand that infrastructure projects respond to environmental challenges and people start to realise the negative consequences of not to pursue sustainability. Stakeholders are now keen to identify sustainable alternatives and financial implications of including them on a whole lifecycle basis. Therefore tools that aid the evaluation of investment options, such as provision of environmentally sustainable features in roads and highways, are highly desirable. Life-cycle cost analysis (LCCA) is generally recognised as a valuable approach for investment decision making for construction works. However to date it has limited application because the current LCCA models tend to focus on economic issues alone and are not able to deal with sustainability factors. This paper reports a research on identifying sustainability related factors in highway construction projects, in quantitative and qualitative forms of a multi-criteria analysis. These factors are then incorporated into existing LCCA models to produce a new sustainability based LCCA model with cost elements specific to sustainability measures. This presents highway project stakeholders a practical tool to evaluate investment decisions and reach an optimum balance between financial viability and sustainability deliverables.

Key words: highway infrastructure, cost analysis, life-cycle, sustainability.

1. INTRODUCTION

The concept of sustainability has added a new dimension to the evaluation of highway investments. Sustainability means analysing the entire life of a facility, from an environmental as well as economic perspective (List 2007). Keoleian et al. (2005) developed an integrated life cycle assessment and cost model to evaluate infrastructure sustainability, and compared alternative materials and designs using environmental, economic and social indicators. Despite an increasing enthusiasm to propose the Life-cycle cost (LCC) approach as useful in the sustainability context, the adoption and application of LCC in the highway infrastructure sector still remains limited (Chan *et al.* 2008, List 2007, Wilde *et al.* 2001, Zhang *et al.* 2008). Cole and Sterner (2000) indicate that 'imperfect understanding' of LCC's merits among practitioners is the main cause for its limited adoption. There is still a gap between theory and practice as neither of them sufficiently explains the underlying reasons for indicating social and environmental costs into LCCA. The actual incorporation of costs incurred for pursuing social and environmental matters in the LCC approach is not sufficiently clarified:

- Most existing LCCA studies emphasise the cost allocation and investment evaluation of highway projects. These studies are primarily concerned with direct market costs, such as road construction and maintenance costs and crash damages and how these vary depending on roadway conditions. They assumed that the roadway conditions and requirements would not change in a highway lifetime and so were unconcerned with the upgrading and end of life costs (Quinet 2004).
- Existing studies incorporate costs incurred from environmental impacts, primarily air pollution, noise and water pollution and various categories of land use impacts. Some studies have only considered them as external costs. Their results often differ significantly, but can usually be explained by differences in their methodology and scope (Quinet 2004).
- Existing studies also show unclear boundaries in identifying costs incurred for pursuing sustainability matters in highway infrastructure. Some researchers have considered the global impacts of sustainability while others only considered micro impacts (List 2007, Wilde *et al.* 2001, Zhang *et al.* 2008).
- Surahyo and El-Diraby (2009) highlighted that the inconsistent estimation methods in current studies in estimating sustainability-related costs for highways. Some use socioeconomic approaches, while others use technical/ engineering approaches. Due to the subjectivity of sustainability and the soft factors of the related cost components, it is become difficult for current research to create consistent estimation methods.
- Highway infrastructure projects also take place in different physical, legal, and political environments, and studies assessing and mitigating costs incurred for pursuing sustainability matters are still evolving. Therefore, it is difficult to develop a universal standard to address this forecast sustainability-related cost component estimation methods (Surahyo and El-Diraby 2009).

These limitations show the significance and necessity of incorporating costs of pursuing sustainability measures into LCC practice. This research attempts to propose a financial decision support model to deal with highway investment decisions with sustainability objectives and action plans..

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2. COST IMPLICATIONS FOR SUSTAINABLE MEASURES IN HIGHWAY PROJECTS

Realising the advantages of pursuing sustainability, some research projects attempt to investigate topics bridging the gap between sustainability and highway infrastructure. For example, Huang and Yeh (2008) have implemented an assessment rating framework for green highway projects. In the study, the framework has been developed to analyse and measure the achievement of sustainability in the highway infrastructure by using several indicators. In addition, Ugwu et.al (Ugwu *et al.* 2006a, 2006b) found that there is a desire of methods and techniques that would facilitate sustainability assessment and decision making at the various project level interfaces during the development phases of a project.

Although sustainability concept is essential and current for Australian highway infrastructure development, stakeholders also realise the long-term cost implications for the investments. Due to the reason that decisions based solely on acquisition cost may not turn out to be the best selection in the long run, Surahyo and El-Diraby (2009) highlighted the need of assessing both environmental and social costs in highway projects. There is a general consensus among stakeholders that sustainability endeavours will have an impact on the developmental costs of highway infrastructure.

While the sustainability concept is being emphasised in highway infrastructure, effective management of highway investment becomes crucial as highway funding at all levels of government continues to fall short of infrastructure needs. In this regards, life-cycle cost analysis (LCCA) is applied to explore the more efficient investment for the stakeholders. It evaluates not only the initial construction cost of the highway infrastructure, but also all the associated maintenance costs during its service life. Hence, it produces a decision support tool for the stakeholders to select the most appropriate design with the consideration of financial benefit in the long run.

The concept of LCCA was firstly applied in highway development by AASHTO “Red Book” in 1960s (Wilde *et al.* 2001). Since this conception, it has not been applied widely for a few decades until the early 90s when the Federal Highway Administration (FWHA) started promoting the use of life-cycle costs in the design and using of highway infrastructure. The promotion was supported by the United States government who imposed a new requirement making LCCA compulsory in the National Highway System (NHS) projects that cost over $25 million (Chan *et al.* 2008). This highlighted that the applications of LCCA in highway infrastructure in practice start to take shape as the stakeholders realise the importance of long term investment for highway infrastructure.

The use of LCCA in highway infrastructure seems established, but there are still limitations on the current LCCA models. These models are not well-established and have not covered some critical issues in highway development. Wilde et al. (2001) reported that the consideration of social impacts of road construction, including health impacts of pollution emission, noise and etc, was still independent of other costs and the incorporation of these cost components into LCCA has not been undertaken.

This study realised the need and potential to incorporate these cost components into LCCA in order to capture the full costs of highway development, under the increased pressure on achieve sustainability. It works towards building an expanded LCCA model that incorporates sustainability benefits assessment in financial decisions for highway infrastructure.

3. RESEARCH METHODOLOGY

This research employs triangulation of literature review, questionnaire surveys and semi-structured interviews to gather relevant data in the construction industry. A survey is a means of "gathering information about the characteristics, actions, or opinions of a large group of people, referred to as a population" (Bernard 2006). As such, there are many data collection and measurement processes that are called surveys; questionnaire-based surveys, marketing surveys, opinion surveys and political polls to name some of the most common.

To identify the relative importance of cost components related to sustainable measures, the information in relation to these cost components must be collected through questionnaires. The literature findings have demonstrated that the lack of the effective ways in quantifying these cost components and the limitation of current LCCA model in handling them. The needs and overall situation of the current LCCA practice in Australian highway industry would rely on the realistic semi-structured interviews. In spite of the rare literatures relating to the research context, the semi-structured interviews can provide both information as facts of the practice and opinions from the professional experience. The information can be the initial source for the further knowledge base formulation along with the decision support development to achieve the goal in this research. To get an understanding of current status of the Australian highway industry in handling highway investment, the industry stakeholders have been the major subjects. The questionnaire surveys and semi structured interviews were carried out in the major states of Australia.

3.1 Industry Questionnaires

This study used questionnaire-based surveys as the domains for the researcher to identify the sustainability-related cost components in highway infrastructure. Questionnaire surveys were selected because they are effective in gathering information about the characteristics, actions, or opinions of a large group of people (Creswell 2009).

Based on the comprehensive review of literature, 40 sustainability-related cost components were identified. This provides a platform to formulate the questionnaire survey. To refine these components and questions in the questionnaire survey, a pilot study was accomplished with three academic experts and six industry experts. This process resulted in several improvements and changes to the questionnaire, to improve participants’ understanding of the questions. Based on this pilot study, a list of 42 sustainability-related cost components was included in the final version of the questionnaire.

The questionnaire survey was administered by on-line questionnaire between June and August 2009. A total of 150 questionnaires were delivered to survey participants with a covering letter explaining the purpose of the study and the assurance of anonymity. Typical participants (local authorities and government officers, project managers, engineers, quantity surveyors, planners, contractors and subcontractors) represent 70+ organisations throughout Australia are selected for their recent involvement in highway development. The good level of support from stakeholders in the highway industry allowed 43% response rate.

Out of a total of 150 questionnaires sent out, 71 questionnaires were returned and nine were not completed in full. As a result, the useable response rate was 42% or 62 questionnaires. Participants were asked to rate the importance of each cost component in LCCA consideration for highway project.

Most participants have more than 20 years of experience in highway construction. They are in the project management levels so they express their interest in emphasising sustainability concepts in LCCA practice. These participants are categorised into 3 main category namely, consulting, contractor and government agency. The representatives distribution of the respondent by categories are quite reasonable showing the largest amount the government agencies and local authorities (53%), and the remainder were contractors (24%) and consultants (23%). This reflects the respondents participate in this study with the ratio of "Consultants 1: Contractors 1: Government Agencies and Local Authorities 2".

3.2 Semi-Structured Interview

The main objectives of interviews were to explore the different perceptions, expectations of various stakeholders regardless to the current practice of long-term financial management in highway project in Australia. Face-to-face and telephone interview approaches were employed in this study. Due to the geographical limitation, telephone interview was employed for the interviewees outside Queensland. The interviewer managed to control the pace of both interview approaches and record any data that were forthcoming.

The face-to-face and semi-structured interview approach was employed in this research in the following contexts and stages:

- After questionnaire survey stage which aimed to achieve the objectives of identifying the different perceptions, expectations of various stakeholders regardless to the current practice of long-term financial management and understanding the determination and calculation of sustainability related cost components in highway project in Australia; and
- In relation with case studies at a later stage to elicit information from case study projects.

As identified in the questionnaire survey, there was difference in the various stakeholders' perceptions of cost components related to sustainability measures in highway projects. Accordingly, the semi-structured interviews that were conducted at the middle stage of data collection after questionnaire survey uncovered the in-depth understanding and perceptions of current practice of long-term financial management of the different interviewees, and the author was able to determine how the sustainability-related cost components be calculated and unquantified variables needed further in-depth investigation.

Thirteen senior practitioners from Australian highway industry were interviewed. Specifically, there were 8 interviewees from government departments, 2 from private companies and 3 from research or academic institutions. A majority of these (10 or 77%) held senior to top management positions and possessed decision-making roles in their respective organisations, while others (3 or 23%) are the senior researchers in this area.

The professions of the respondents are classified into three categories: Government Officers (46%), Researchers (23%), Consultants (15%) and Contractors (15%). In particular, the government officers include managers in selected disciplines such as asset strategies, asset and network performance and road transport policy and investment. The researchers encompass the professors and senior research fellows involved in highway infrastructure research. Consultants and contractors cover senior civil engineers, builders and network managers involved in highway design and transportation management.

Meanwhile, since the questionnaire feedbacks covers several states in Australia, interviews were organised in these cities such as Sydney, Melbourne, Perth and Brisbane. Prior to the interviews, questions were sent to the interviewees by email for their early perusal and preparation.

4. RESULTS AND FINDINGS

This research uses the mean indexing to support criticality index to rank the cost components related to sustainable measures, the level of importance was based on their professional judgment on a given five-point Likert-scale from 1 to 5 (where 1 is not important at all and 5 is very important). Higher mean scores reflect responses that indicate the higher importance of the respective cost components. The critical rating was fixed at scale '3.75' since ratings above '3' represent 'moderate important', '4' represent 'important', and '5' represent 'most important' according to the scale. Likert scales facilitate the quantification of responses so that statistical analysis could be taken and observed the perceptions of differences between participants. The descriptive statistics were employed to analyse the survey results on the critical cost factors.

Upon completion of the interviews, the opinions of the interviewees on the questions were recorded and then transcribed into text documents using the aid of software and Microsoft Word. In order to improve the accuracy of the transcriptions, the comments from the interview were first transcribe by the software called Macspeech Scribe Version 1.1. Once the transcription has finished, the researcher listened the transcription again and filled the gap where the software cannot handle as well as check on the mistakes that occurred by the software. Once finished editing the transcription, the researcher listened the recorded interview again as well as checking on the consistency between the transcription as well as the comments and opinions from the interviewees. Their opinions were categorised and grouped under different headings. This allowed systematic and thorough analysis of their comments on the overall stakeholders' perspective of integrating sustainability-related cost components in LCCA. The findings were discussed accordingly.

4.1 Cost implications for Highway Sustainability

Based on the analysis of the results, the rating of importance level in Table 1 revealed that the top scoring cost components are centred on three major sustainability aspects in terms of agency, social and environmental categories. The following sections elaborate on these findings.

4.1.1 Agency cost components

Agency costs comprise of all costs generated by the highway agencies' activities over the overlay system lifetime. These typically include construction and preservation costs such as material, plant and equipment and labour costs. As highlighted by the participants, material costs (mean = 4.40) and plant and equipment costs (mean = 4.16) are the top main cost categories ranked by the stakeholders. This finding is also consistent with the viewpoint of previous literature (Singh and Tiong 2005, Tighe 2001, Ugwu *et al.* 2005). These costs are selected because of the significant amount of capital needed for addressing the concerned aspects during the constructions stage.

Meanwhile, participants also ranked that major maintenance and rehabilitation costs (Mean = 4.06) are the third most important in highway investment. They stated that rehabilitation activities are important to preserve the effectiveness of transportation, safety of road users and economic development. As mentioned by Rouse and Chiu (2008), the quality of roads deteriorates over time. Hence, proper maintenance of the highway system is necessary to preserve its serviceability and structural reliability. Since highways need to last over a long time span, maintenance activities should be considered from a life-cycle perspective. An optimal balance between benefits and costs is crucial to achieving long-term financial viability while ensuring the best service to road users.

Moreover some factors are more important according different stakeholders. For example, pavement recycling costs were ranked as the third most critical based on contractors' perception. According to Widyatmoko (2008), recycled materials are more cost effective compare to conventional materials. In the meantime, they also preserve similar performance to the pavement. Thus, contractors are increasingly concerned with sustainable development and the emphasis on material conservation and re-use such as recycling of pavement during highways maintenance and rehabilitation activities.

4.1.2 Social cost components

Road accident costs have emerged as the most important theme in the social aspects. These costs refer to the economic value of damages (Mean = 4.10) caused by vehicle crashes which includes internal costs, those incurred due to damages and risks to the individual travelling in a particular vehicle; and external costs, which are uncompensated damages and risks imposed by an individual on other people (Partheeban *et al.* 2008). Road accident-internal costs (Mean = 4.23) were ranked as the most important criteria because highway safety is becoming a main agenda. Highway construction needs to improve general access for the community while highway upgrade, maintenance and rehabilitation help improve road safety for users. Often decisions regarding highway design selection are based not only on the development of financial budget, but also on the design safety for road users. Thus, road accidents costs are become a primary concern in the social aspects of LCC analysis for highway projects.

Traffic congestion (Mean = 4.00, 3.79) receives high importance ranking among social category by the contractors and consultants. Heavy traffic tends to degrade the public realm (public spaces where people naturally interact) and in other ways reduce community cohesion (Litman 2007). Highway traffic certainly involves traffic delay costs to users that have been mathematically modeled and evaluated based on simplifying assumptions (Jiang and Adeli 2003). Respondents commented that the design and construction of highway infrastructure is critical because of the natural increase and interstate migration that influences the growth of traffic in South East Queensland. Therefore, this situation puts significant pressure to highway infrastructure development.

Nevertheless, because of the increasing usage of highway infrastructure, renewal works are needed in some periods. Surplus funds are needed to ensure that renewal or extension works can take place during the highway life span. This situation becomes a challenge to the stakeholders to optimise the desired service levels while minimising life-cycle costs for highway infrastructure.

4.1.3 Environmental cost components

Highway systems produce a mixture of impacts on the environment, and costs involved in environmental issues also vary depending on the situation and the nature of the project (Surahyo and El-Diraby 2009). Water pollution, such as loss of wetland, and hydrological impacts, are ranked as the most important by the government agencies and local authorities. They highlighted that these impacts impose various costs including those related to polluted surfaces and ground water, contaminated drinking water, increased flooding and flood control costs, loss of unique natural features, and aesthetic losses. Quantifying these costs is challenging. It is difficult to determine how many motor vehicles contribute to water pollution problems since impacts are diffused and cumulative.

Ground extraction costs, disposal of material costs, and waste management costs are the top three environmental cost components ranked as significant by the contractors and consultants. Solid waste is usually generated during the construction, maintenance and rehabilitation stages of highway infrastructure. This waste imposes a variety of environmental, human health and aesthetic costs. Some legislations and policies are designed to ensure that the disposal of materials is properly managed (Hao *et al.* 2007). Therefore, legislations make it mandatory for the stakeholder to prepare a relevant budget for managing the disposal of solid waste.

4.2 Integrating Cost Related to Sustainable Measures

Current construction industry faced many challenges of integrating cost components related to sustainable measures in LCCA, as indicated by the comments from the survey and also some of the current literature studies. These issues might be due to the current industry practices and also the difficulties to quantify these costs. Prior to the analyses of the feedback on the potential issues, the interviewees' perspective and comments on current industry practice on LCCA and the ways in dealing with sustainability-related cost components are studied to determine the reality based of industry experience.

4.2.1 Current Industry Practice on LCCA Application

Based on the results from the interview, it can be concluded that life-cycle cost analysis is important in highway infrastructure management. Though some of the regions apply LCCA while other use benefit-cost analysis, the stakeholders do have some general understanding on the details of each application and details of the LCCA approach. Their opinions have direct connection to their profession and organisation. They do agree that the incorporation of sustainability concept into LCCA is important to deal with highway investment in the future. It is essential to improve current calculation methods in dealing with sustainability-related cost components. The following sections are discuss in more detail how the industries deal with the sustainability-related cost components in highway infrastructure.

4.2.2 Ways to Quantify Sustainability-Related Cost Components

The feedback from the interviewees indicates that in terms of agency cost categories, they are able to quantify these costs based on the existing models and programs. They also use historical data as a guideline in dealing with these costs. The social and environmental costs are still not very clear in the estimation methods. Some of the interviewees mentioned that they use a wrap up cost, other mentioned using the environmental impact assessment as their guideline, and the rest said that it is very hard to convert each of the components into real costs money.

Table 1: Perceptions of 'Importance Level' costs components related to sustainable measure by industry stakeholders

Sustainability indicators	Sub cost components	Mean (SD, Ranking)			
		All (N=62)	Government Agencies and Local Authorities (N=33)	Contractors (N=15)	Consultants (N=14)
Agency Category	Material costs	4.40 (0.74, 1)	4.30 (0.81,1)	4.50 (0.65, 1)	4.57 (0.65, 1)
	Plant and equipment costs	4.16 (0.77, 2)	4.09 (0.77, 4)	4.19 (0.91, 2)	4.36 (0.63, 2)
	Rehabilitation costs	4.06 (0.87, 3)	4.21 (0.65, 3)	3.94 (1.17, 3)	3.93 (1.00, 5)
	Major maintenance costs	4.06 (0.89, 3)	4.24 (0.83, 2)	3.81 (0.91, 6)	4.00 (0.96, 4)
	Labour costs	3.87 (0.91,5)	3.82 (0.77, 6)	3.88 (1.29, 5)	4.07 (0.83, 3)
	Routine maintenance costs	3.84 (1.06, 6)	4.06 (1.00, 5)	3.44 (1.09, 8)	3.86 (1.10, 6)
	Recycle costs	3.44 (1.15, 7)	3.21 (0.99, 8)	3.94 (1.23, 3)	3.43 (1.34, 8)
	Dispose asphalt materials costs	3.29 (1.07, 8)	3.00 (1.00, 10)	3.63 (1.12, 7)	3.50 (1.02, 7)
	Demolition costs	3.13 (1.18, 9)	3.24 (1.12, 7)	3.00 (1.12, 9)	2.86 (1.41, 9)
	Pavement extension costs	3.02 (1.02, 10)	3.09 (1.07, 9)	3.00 (1.00, 9)	2.86 (0.95, 9)
Social Category	Road accident- internal costs	4.23 (0.99, 1)	4.45 (1.79, 1)	4.25 (0.97, 1)	3.64 (1.22, 5)
	Road accident- economic value of damage	4.10 (0.92, 2)	4.39 (0.79, 2)	3.81 (1.00, 4)	3.71 (0.99, 3)
	Road accident- external costs	3.84 (1.14, 3)	4.00 (1.12, 3)	3.88 (1.00, 3)	3.43 (1.28, 6)
	Vehicle operation costs	3.71 (1.07, 4)	3.67 (1.11, 5)	3.75 (1.20, 5)	3.79 (0.89, 1)
	Traffic congestion	3.71 (1.26, 4)	3.55 (1.23, 7)	4.00 (1.18, 2)	3.79 (1.42, 1)
	Resettling cost	3.53 (1.16, 6)	3.58 (1.30, 6)	3.44 (1.09, 7)	3.43 (0.94, 6)
	Reduction of culture heritage	3.50 (1.10, 7)	3.82 (1.16, 4)	3.06 (0.83, 10)	3.29 (1.07, 8)
	Community cohesion	3.40 (1.21, 8)	3.48 (1.28, 8)	3.38 (0.94, 8)	3.14 (1.35, 10)
	Reduce speed through work zone	3.37 (1.30, 9)	3.18 (1.26, 10)	3.56 (1.33, 6)	3.64 (1.34, 4)
	Negative visual impact	3.35 (0.95, 10)	3.39 (1.09, 9)	3.25 (0.51, 9)	3.29 (0.99, 8)
	Property devaluation	3.03 (0.98, 11)	3.12 (1.11, 11)	3.06 (0.92, 10)	2.79 (0.70, 12)
	Road tax and insurance	2.84 (1.15, 12)	2.79 (1.17, 12)	3.00 (1.24, 12)	2.86 (1.10, 11)
Environmental Category	Hydrological impacts	4.08 (0.88, 1)	4.36 (0.82, 1)	3.63 (0.80, 12)	3.86 (0.95, 3)
	Loss of wetland	4.05 (0.88, 2)	4.24 (0.83, 2)	3.88 (0.92, 5)	3.71 (0.91, 6)
	Disposal of material costs	4.00 (1.05, 3)	3.97 (1.02, 7)	4.13 (0.97, 1)	3.86 (1.23, 3)
	Cost of barriers	3.98 (0.97, 4)	4.21 (0.96, 3)	3.69 (0.95, 10)	3.64 (0.93, 9)
	Dust emission	3.94 (1.05, 5)	4.00 (1.12, 5)	3.94 (0.86, 4)	3.71 (1.07, 8)
	Ground extraction costs	3.92 (0.92, 6)	3.85 (0.87, 10)	4.06 (0.86, 2)	3.86 (1.10, 2)
	Habitat disruption	3.84 (0.88, 7)	3.97 (0.92, 8)	3.69 (0.70, 10)	3.57 (0.94, 12)
	Land use	3.84 (0.98, 7)	4.06 (0.97, 4)	3.38 (0.94, 17)	3.71 (0.99, 6)
	Waste management costs	3.84 (1.09, 7)	3.70 (1.10, 16)	4.00 (0.97, 3)	3.93 (1.14, 1)
	Soil disturbance	3.79 (0.87, 10)	3.82 (0.85, 13)	3.75 (0.88, 9)	3.64 (0.93, 9)
	CO2 emission	3.79 (1.14, 10)	3.73 (1.15, 15)	3.88 (1.04, 5)	3.79 (1.25, 5)
	Extent of tree felling	3.77 (0.93, 12)	3.85 (1.00, 11)	3.63 (0.97, 12)	3.64 (0.74, 9)
	Rough surface produce more tyre noise	3.73 (1.07, 13)	4.00 (1.00, 5)	3.50 (0.94, 15)	3.21 (1.19, 15)
	Ecological damage	3.69 (0.99, 14)	3.85 (1.06, 11)	3.44 (0.85, 16)	3.50 (0.94, 13)
	Environmental degradation	3.63 (1.02, 15)	3.88 (1.05, 9)	3.38 (0.94, 17)	3.21 (0.89, 15)
	Air pollution effects on human health	3.63 (1.17, 15)	3.79 (1.22, 14)	3.56 (1.08, 14)	3.29 (1.14, 14)
	Fuel consumption	3.40 (1.11, 17)	3.33 (1.16, 18)	3.81 (0.66, 8)	3.07 (1.27, 17)
	Vehicles engine acceleration noise	3.37 (1.19, 18)	3.52 (1.28, 17)	3.25 (0.93, 19)	3.07 (1.21, 18)
	Energy consumption	3.32 (1.01, 19)	3.30 (0.95, 19)	3.88 (0.39, 5)	2.71 (1.20, 19)
	Driver attitudes	3.05 (1.30, 20)	3.15 (1.30, 20)	3.25 (1.09, 19)	2.50 (1.40, 20)

Note: N= Number of respondents, SD= Standard Deviation

From all of these responses, it can be concluded that the current industry lacks knowledge and methods to deal with the social and environmental costs in highway infrastructure. In the following section, the limitations of integrating sustainability-related cost components into LCCA are further discussed.

4.2.3 Challenges of Integrating Costs Related to Sustainable Measures

The feedback from the interviewees revealed that there are two main domains contribute to the different challenges when emphasising sustainability-related cost components into LCCA practice. They are:

- **The omission of social and environmental costs in LCCA:** This is caused by the difficulty of putting a dollar figure on each factors, the difficulty of quantifying social and environmental related costs and unclear impacts on the social and environmental issues.
- **Uncertainty environment:** This is caused by the lack of data in these areas; especially in identifying real cost values for the sustainability-related cost components, the assumptions needed in calculating and identifying these cost components, uncertainties of the future social and environmental impacts caused by highway infrastructure

development, dynamic changes in the environment, the lack of techniques or models in evaluation sustainability-related costs, and changes in the government policies and guidelines.

Based on the overall results highlighted in this section, it can be concluded that there are challenges in applying sustainability concepts in long-term financial management. Although some efforts have been done to consider sustainability impacts on the highway infrastructure, the stakeholders report that more work needs to be done to deal with this uncertainty and also to improve the decision making process in highway investments. The suggestions from industry stakeholders about how to enhance sustainability-related considerations in LCCA for highway infrastructure projects.

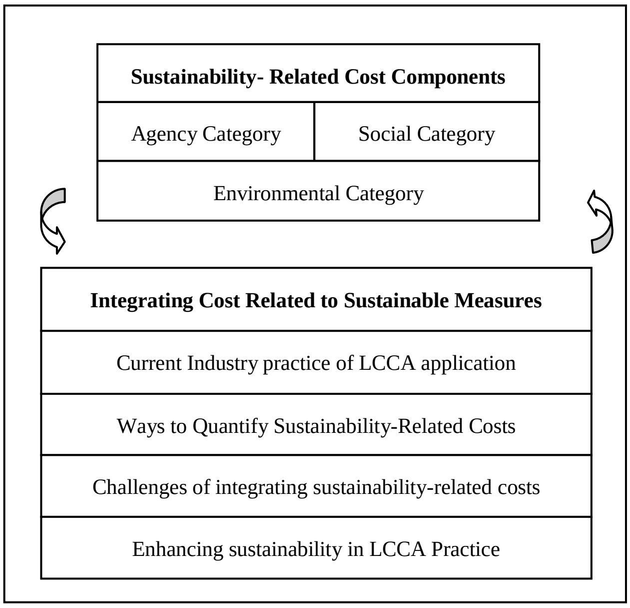

Figure 1: Platform of overall scenario of long-term financial management in highway infrastructure

4.2.4 Enhancing Sustainability in LCCA Practice

The feedback from the interviewees indicates that there are still areas for improvement in current long-term financial management. In order to embed sustainability in long-term financial management, there is a need for tools that are not only able to evaluate conventional cost items but also able to evaluate the importance of sustainability-related issues and impacts on the highway infrastructure investment decisions.

4.2.5 Developing a decision support model

Bringing together findings from sections 4.2.1 to 4.2.4, (critical sustainability-related cost components in highway infrastructure; current industry practice of LCCA application in highway project; challenges of integrating costs related to sustainable measures into LCCA practice; and stakeholders' perception towards sustainability enhancement for LCCA), a platform depicting the overall scenario of long-term financial management with sustainability objectives in highway infrastructure development has been established as shown in Figure 1. The platform presents a way in probing into the current industry practice and general perceptions held by the various stakeholders in long-term highway infrastructure investment with sustainability objective. Premised on this platform, the study advances into its subsequent stage – the development of the decision support model. This on-going development employs the integration of the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) approach, the life-cycle costing analysis (LCCA) concept and the sensitivity analysis. It will provide a procedure driven and guidance enhanced tool that will enable stakeholders to make financial decisions on embeding sustainability initiatives into highway development. Real world case studies will be used to test and evaluate the model as the final step.

5. CONCLUSIONS

The pursuit of sustainability in highway development may have long term financial implications to the involved stakeholdkers. By understanding the overall status and challenges, strategies to improve and encourage these industry practitioners to enhance long-term financial positions while maximising sustainbility deliverables can be developed and articulated. This provides the foundation for a decision support model that is capable of handling cost associated with sustainability measures in highway projects. Innovation such as this will help ensure that decisions on highway investment can be made on scientific and systematic basis particularly when they concern with sustainability issues.

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